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Expanded Capability of the Edge Charge-Exchange Recombination Spectroscopy System on JET

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A new instrument has been added to the Joint European Torus (JET) edge charge-exchange recombination spectroscopy (CXRS) suite of diagnostics. The new instrument consists of a short focal length spectrometer coupled to a fast framing CCD camera. With the addition of this instrument, the number of (predominantly poloidal) sightlines is increased by 20 to a total of 58 views. The radial range of the edge CXRS system extends from $r/a \sim 0.5$ to ~ 1.0. The time resolution of this instrument is 10 ms, but can be improved to 5 ms. This instrument observes the neutral-beam induced charge-exchange emission of C VI at 529 nm and of Ne X at 524 nm simultaneously, complementing the existing edge CXRS instruments, which can be tuned to observe any visible wavelength of interest. The entire edge CXRS diagnostic suite has been absolutely calibrated and provides measurements of impurity ion temperatures as well as the toroidal and poloidal components of impurity ion rotation. An overview of the edge CXRS diagnostic system on JET will be presented. Preliminary data will be shown from the current JET campaign. In particular, the temporal and spatial improvements afforded by this instrument will provide additional data during the formation of ion internal transport barriers (ITBs) in JET, especially on the relative timing and location of emerging rational-q flux surfaces and poloidal flow spin up.

Introduction

The observation of visible light emitted by plasma impurity ions, excited by charge-exchange interaction with injected neutral-beam ions is generally referred to as charge-exchange recombination spectroscopy (CXRS)[1]. Prior to the charge-exchange interaction, the emitting ions are assumed to in thermal equilibrium with the "bulk" plasma, and hence the thermal broadening of the CX emission lines are taken to be indicative of the ion temperature of the bulk plasma. Similarly, with ion-species-dependant corrections, the impurity ion velocity (measured

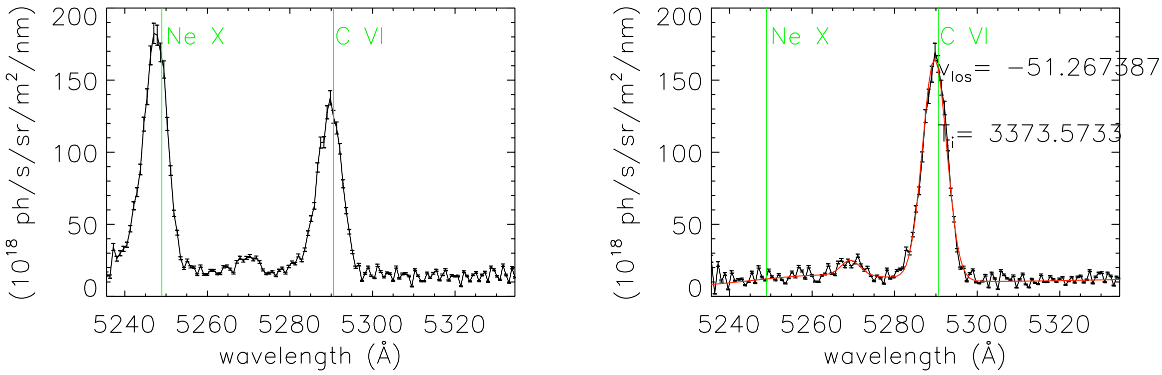

Figure 1: *Sample spectra from the new edge CXRS instrument showing the spectral coverage afforded by the band-pass filter and the relative location of the Ne* X *and C* VI *CXRS lines with and without neon puffing for pulse 72428.*

by the doppler shift of the spectral line) can be related to the bulk plasma rotation velocity. If the instrument has been calibrated by a light source of known radiance, then the concentration of observed impurity ions in the plasma can also be inferred.

The CXRS suite of diagnostics on the Joint European Torus (JET)[2] is delineated into two categories: instruments which observe (∼toroidally) the core[3, 4] of JET plasmas, and those which observe (poloidally and toroidally) the edge[5]. Recently an additional instrument has been added to the edge CXRS suite of diagnostics, expanding the capability of the measurement systems.

The Light Detection System

The new edge CXRS instrument consists of a short focal length spectrometer commercially available from Kaiser Optical System[6], coupled to a fast framing Princeton Instruments[7] PhotonMax CCD camera. This type of instrument[8] has been utilized both at JET[4] and elsewhere[9, 10]. A mechanical chopper[11] is used to prevent the unwanted exposure of pixels while the CCD is read out[12]. The spectrometer is a Holospec $f/1.8$. It is designed to accommodate either a "low dispersion" transmission grating, or a "high dispersion" holographic grating, both at fixed observation wavelength. In the "low dispersion" configuration utilized here, the grating is ruled for a center wavelength of 529.1 nm, i.e the $n = 8-7$ C VI CXRS line. Two (curved[8]) input slits are used, with 10 fibers/slit. A 10 nm band-pass spectral filter, centered on 529 nm, is used to make horizontally adjacent regions of the CCD spectrally distinct. The $n = 11-10$ Ne X CXRS line at 524.9 nm is contained within the filter passband. In this way 20 views of 2 CX lines are accommodated on the CCD chip. See Figure 1. The CCD is a back-illuminated 512×512 array of 16×16 μm pixels with a 16 bit well depth, which is thermo-electrically cooled to -70 °C to reduce dark current noise. "On-chip binning" is utilized to reduce read-out time. The system can be run with a 5 ms framing period, light levels permitting. In this instance, however the framing period is 10 ms, in accordance with the design of the chopper.

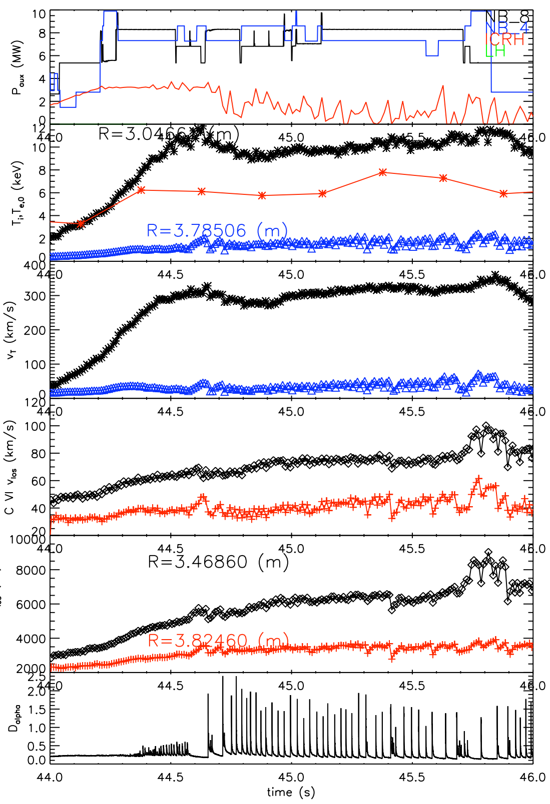

Figure 2: *Data during JET pulse 72743, showing (a) the auxiliary power, (b) "core" CXRS measured T_i at two different radii and $T_{e,0}$ from LIDAR (red), (c) toroidal rotation, v_ϕ, (d) "edge" CXRS measured line-of-sight rotation at two radii from the C VI line, (e) apparent temperature, and (f) a D_α trace.*

Photons are collected from JET plasmas via 3 separate "periscopes", which are described elsewhere[5]. Light is transferred from the JET experimental hall to the diagnostic room via 600 μm diameter fiber optics. The light is distributed to the edge CXRS suite of instruments at a break-out panel in the diagnostic area. In principle, the light from any periscope view can be coupled to any edge CXRS instrument. In practice, a fixed number of configurations is utilized. The instrument described here operates at fixed wavelength. Other edge CXRS systems are tunable wavelength instruments, allowing other CX lines to be observed. Together, the edge CXRS suite of diagnostics provides a flexible array of instruments measuring the dynamics of ion species in JET plasmas. There are 58 total views measured, resulting in radial coverage from $r/a \sim 0.5$ to ~ 1.0 with a sample volume whose radial extent varies from ~ 12 cm on the core-most views to < 1 cm on the edge-most views. The sight-lines are predominantly poloidal, but have a consequential toroidal component, due to the manner in which the neutral beam volumes are observed.

Results

Work is ongoing to incorporate the analysis of data from the edge CXRS system into the standard charge-exchange analysis packaged called `CXSFit`.[13] This will facilitate direct comparison between this new edge CXRS instrument, the other remaining edge CXRS instruments, and the core CXRS suite of instruments. In this paper only line-of-sight measurements will be reported, since the incorporation of this instrument into `CXSFit` has not been completed. Fig. 2 shows the time evolution of line-of-sight ion temperature, T_i, and line-of-sight rotation, v_{los}, as measured by the new edge CXRS instrument; along with the core CXRS measured toroidal rotation, v_ϕ, and T_i for comparison. An ion internal transport barrier (ITB)[14] crosses the $\rho^*_{Ti} = 0.020$ threshold at $t \sim 45.6$ s at $R \sim 3.45$ m. The presence of the ITB in the $\sim$poloidal dynamics is clear on the edge CXRS sightline that samples this radius.

Summary

A new instrument is described, which enhances the coverage of the JET edge CXRS suite of diagnostics. Some preliminary data for the current JET experimental campaign is shown, but more thorough analysis is underway.

Acknowledgments

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